Testing of Building Products for Emissions of Volatile Organic Compounds: Practical Time Point for Assessing Potential Chronic Health Impacts

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Introduction

Many products used to finish the interiors of buildings are emission sources of a broad range of volatile organic compounds (VOCs). The general population, including children and other sensitive individuals, experience inhalation exposures to these compounds in new and renovated buildings. The most important potential exposures with respect to public health are those that can result in moderate to serious systemic impairment that does not reverse itself when an occupant leaves the building. These effects are due to relatively long-term exposures at concentrations often well below levels that: (a) cause odors or sensory irritation; or (b) are thresholds considered safe for workers in industrial settings. The architectural specification that is known as "Special Environmental Requirements, Specification Section 01350" (CHPS, 2002; CDHS, 2004) was developed as a building product testing and evaluation protocol with the goal of reducing the exposures of occupants of new and renovated buildings to VOCs with known non-carcinogenic chronic health effects. The specification does not purport to address all toxicants or health effects potentially associated with emissions from all types of building products or their installation practices.

Specification Section 01350 utilizes air quality guidelines that were developed by the California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (OEHHA). This agency has taken an active role in developing peer-reviewed health assessments for air contaminants using the latest literature. This ongoing effort has resulted in the establishment of noncancer chronic Reference Exposure Levels (RELs) for a number of VOCs widely used in industry (OEHHA, 2002). Currently the list contains 78 chemical substances. These chronic RELs are concentrations at or below which noncancer adverse health effects are unlikely to occur among a diverse population (including sensitive individuals) from chronic continuous exposure.

The chronic RELs for common VOCs were selected as the air quality guidelines for Specification Section 01350. The laboratory protocol for the specification was designed to provide data useful for assessing the impacts of products on relatively long-term concentrations of these chronic VOC toxicants. Specifically, a sampling time point of sufficiently long duration was needed to measure the characteristic diffusion controlled emission rates of VOCs from solid products. Secondly, the test duration and design had to be practical with respect to fast-paced building schedules and to the costs associated with conducting emission tests. The testing protocol was based on a substantial body of preceding

European test protocols and from prior empirical and theoretical studies of VOC emissions from common building products. A portion of that literature is reviewed below.

Empirical Data

A project entitled, "Common Indoor Sources of Volatile Organic Compounds: Emission Rates and Techniques for Reducing Consumer Exposures," was conducted by Lawrence Berkeley National Laboratory for the California Air Resources Board in 1995-1998 (Hodgson, 1999). The investigation characterized the emissions of VOCs from interior latex paints and newly manufactured carpet and vinyl flooring products. Screening measurements were made in small-scale chambers over 48 or 96 hour and, based on these screening results; products were selected for study in large-scale chambers simulating a small room in a house. Thirteen large-scale experiments were conducted in total; 11 were with individual assemblies (paint, carpet and cushion, or vinyl flooring) and two were with all three assemblies combined. The experimental period was 14 days with frequent sample collection, and one experiment with the combined assemblies was extended to three months. A variety of ventilation, air mixing, and temperature settings were applied either prior to the experiment (i.e., airing out of materials) or within the first three days of the experiment (i.e., additional ventilation, additional air mixing for paints, and heating to 33 ^{o}C versus the standard 23 ^{o}C).

The large-scale experiments provide information on the temporal course of emissions over the first two weeks following installation of common products used to finish interiors of buildings. Data for the predominant compounds (both concentrations and area-specific emission rates) in general show large decreases in concentrations and emission rates over the first several days and slowly declining values from approximately 96 hours through the end of the two-week period. One exception was the emission rate of butylated hydroxytoluene (BHT) emitted by carpet cushion, which increased with time. A notable finding was that additional ventilation and/or heating applied in the first three days of the experiments had, in most cases, negligible effects on emission rates at later time periods.

These large-scale chamber results were considered in the design of a 1999-2000 field study to identify the sources of formaldehyde, other aldehydes and terpene hydrocarbons in a new manufactured house (Hodgson et al., 2002). One objective was to use VOC emission rates determined in small-scale chambers for the major interior materials to predict emission rates in the house several months after it was completed. In order to accomplish this objective, it was important to measure emission rates at a practical time point when the rates would be expected to change slowly with time and to be characteristic of the long-term diffusion controlled rates. Thus, all test specimens were conditioned at controlled conditions for 19 ± 4 days prior to a 48-h test in a small-scale chamber, i.e., the measurements were made at three weeks following specimen preparation. The conditioning period and chamber exposure time are closely similar to those previously used by Salthammer (1997) as discussed below. Measurements of VOC concentrations and the ventilation rate in the house were used to derive emission rates for individual compounds. These were compared to emission rates predicted based on the chamber measurements and the quantities of materials used in the interior of the house. For 10 of 14 major compounds, the predicted emission rates agreed with the derived rates within a factor of two, which is a reasonable boundary for acceptable agreement in this type of study.

In 2001, a similar laboratory and field study was conducted with relocatable classrooms in California (Hodgson et al., In press). In this study, products for finishing the interiors of two classrooms were selected with the goal of reducing potential exposures to toxic air contaminants with serious chronic health effects, i.e., chemicals with chronic reference exposure levels established OEHHA. For practical considerations, the total testing time for products was reduced from three to two weeks, which consisted of a 10-day conditioning period followed by a four-day chamber test. Four classrooms consisting of two source modified classrooms and two control classrooms were constructed and sited at two schools. Extensive measurements of VOC concentrations were made over two semesters in the four classrooms. Indoor minus outdoor concentrations of 15 VOCs measured when the classrooms were operating near the code-minimum ventilation rates in the first semester were compared to predicted concentrations based on the product emissions rates and installed surface areas. For about one-third of the possible comparisons, the predicted and measured concentrations agreed within a factor of two. In a number of cases, the measured values were well below the predicted values.

Salthammer (1997) studied the emissions of VOCs from 44 furniture samples manufactured under different industrial conditions with a variety of coatings. Seventeen of the samples were placed in 1-m^3 chambers immediately after production and chamber concentrations were periodically measured over 30-40 days. Several plots showing the temporal pattern of concentrations are provided in the published paper. As stated, “the shape of the decay curve was typical for most recorded concentration vs. time functions of solvent residues, where a steep decrease was observed within 1-10 days, after which only a slight decay was evident.” Based on these results, the remaining samples were preconditioned in a 40-m^3 chamber for 19 days and then transferred to the 1-m^3 chambers with samples collected at 24 and 72 hour. As stated regarding the 24- and 72-h measurements for each product, “The deviations of the chamber concentrations obtained were less than 20% throughout.”

Other published studies of VOC emissions from building products showing concentration profiles versus time for periods of two weeks or longer generally exhibit the same temporal trends, e.g., the Jensen et al. (1995) characterization of VOC emissions from linoleum.

Theoretical Study

A mechanistic model has been developed and validated for predicting the rate at which VOCs are emitted from diffusion-controlled materials (Cox et al., 2002). This model shows considerable promise for predicting emission characteristics from such sources relative to empirical models which generally are of limited value for extrapolating to other conditions. The model was demonstrated using a commercial grade vinyl flooring material as the source. Specimens were placed in small-scale chambers and VOC chamber concentrations were periodically measured over a period of 30 days. In addition, depth profiles of VOC concentrations were measured in the bulk material before and after exposure in the chamber. The plots of chamber concentration versus time show steeply declining concentrations over approximately the first 80 hours followed by a period in which the concentrations change only slowly with time. The diffusion model, in which all of the parameters were determined using procedures completely independent of the chamber, and the measurements of the bulk materials, provided good correlations to both the chamber data and the bulk profile data. These findings support the belief that emissions from solid materials are primarily controlled by internal diffusion. For this material, both the data and the model show that following a period of initial rapid decay, emission rates stay relatively constant over extended periods.

Other Chamber Protocols

The use of a relatively long test period to assess emissions of VOCs from products with respect to indoor comfort and health effects has strong precedent in European test protocols. Often these test protocols either require or allow conditioning of product specimens under controlled conditions prior to transferring them to environmental chambers. The Swedish National Flooring Trade Association and the Swedish National Testing and Research Institute (1992) in their “Trade Standard: Measurement of Chemical Emission from Flooring Materials,” have specified a method to measure the emissions of VOCs from flooring materials that has been in use for over a decade. This method prescribes the placement of test specimens in a conditioning chamber at $23 \pm 2\ ^{o}C$ before and between measurements. The first measurement is made at 28 ± 2 days and the second is made at 26 weeks using a Field and Laboratory Emission Cell (FLEC) operated for 24 hours. The same conditioning requirements and a 28 day measurement period are specified in the 2002 Finnish, “Emission Classification of Building Materials: Protocol for Chemical and Sensory Testing of Building Materials” (Building Information Foundation RTS, 2002)

The German 2002/2003 “Health-related Evaluation Procedure for Volatile Organic Compounds Emissions (VOC and SVOC) from Building Products,” specifies measurement periods of three and 28 days (AgBB, 2002/2003). The stated purpose of the 28-day time period is “to assess the long-term behavior of the VOC emission from a building product.” The actual tests can be conducted in either small-scale chambers or the FLEC. The test procedures to be used are published as DIN V ENV 13419-1 through -3 (European Committee for Standardization, 1999a-c). This set of documents is undergoing revision and will be issued as ISO/DIS 16000-10 through -12. As stated above, the measurement time points are three and 28 days. For long-term testing (i.e., 28 days or longer), the test specimens can be conditioned in a separate controlled environment and then transferred to the chamber or test cell at least 24-h prior to air sampling.

Practical Solution

The potential for chronic illness due to long-term indoor exposures to toxic air contaminants is a serious concern that is being addressed. For most solid materials, the contributions of VOC emissions to such exposure burdens can be estimated from measurements of long-term diffusion-controlled emission rates. These emission rates are best obtained after the materials have been exposed for a period of one week or longer. Thus, many widely recognized European test protocols have agreed upon a 28-day measurement point. However, considerable experimental data, as well as diffusion theory, suggest that a shorter period of 7 to 14 days will provide nearly equivalent data. For practical reasons related to the cost of fabricating and operating environmental chambers, the test period often is broken up into a period of controlled conditioning followed by 24 or more hours in an environmental chamber or FLEC. The procedure outlined in the CDHS Section 01350 document (2004) represents one practical solution to the problem that is compatible with a normal business work schedule. That is, specimens can be prepared on a Friday and placed into the conditioning environment. On a Monday after 10 days of conditioning, the specimens can then be transferred to small-scale chambers with samples collected on Tuesday, Wednesday and Friday (i.e., 24, 48 and 96 hours).

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